$$R = \phi_{\alpha}/(\phi_e + \phi_\tau) = \phi_{\alpha}/(Total - \phi_{\alpha})$$

Neutron Beam Source	**Pion beam Source**	**Muon damped Sourde**
Neutron decays	**Pion decays**	**Pi decay with absorbed muon**
(e:mu:tau)		
(1:0:0)	**(1:2:0)**	**(0:1:0)**
R~0.26	**R~0.5**	**R~0.66**

R may also have an energy dependence characteristic of the source.

The mass eigenstates loose coherence because of long distances

Assuming the source is many wavelengths from the earth, the oscillations average to the central value. Small variations are a measure of θ_{13} and δ_{CP}

$$P_{\alpha\beta} = \sum_{i=1}^{3} |U_{\alpha i}|^2 |U_{\beta i}|^2$$

Difference in sign interchange; role of 0 and π.

$$= \delta_{\alpha\beta} - 2\sum_{i<j} \mathrm{Re}(U_{\alpha i} U^*_{\alpha j} U^*_{\beta i} U_{\beta j})$$

$$R^{\text{Neutron beam}} \sim 0.26 + 0.30\theta_{13} \cos\delta_{CP}$$

$$R^{\text{Muon damped}} \sim 0.66 - 0.52\theta_{13} \cos\delta_{CP}$$

$$R^{\text{Pion beam}} \sim 0.50 - 0.14\theta_{13} \cos\delta_{CP}$$

Astrophysical telescopes do not distinguish between neutrino or anti-neutrino.

For superbeams at the first maximum: Selecty on neutrino or anti-neutrino.

CP

Even Odd

$$P_{\alpha\beta} \sim 2\theta_{13}^2 \pm 0.09\theta_{13} \sin\delta_{CP}$$

δ_{CP} is supressed

Strong dependence on θ_{13}

Small perturbation

Amplitute of signal

$$P_{\nu_\alpha \to \nu_\beta} = |\sum_k U^*_{\alpha k} e^{-im_k^2 L/2E} U_{\beta k}|^2$$

$$= \sum_k |U^*_{\alpha k}|^2 |U_{\beta k}|^2 + 2\mathrm{Re} \sum_{\mathrm{k>j}} U^*_{\alpha k} U_{\beta k} U_{\alpha j} U^*_{\beta j} e^{-i\Delta m_{kj}^2 L/2E}$$

If E >> L, then

$$P_{\alpha\beta} = \sum_{i=1}^{3} |U_{\alpha i}|^2 |U_{\beta i}|^2$$

The simplest method to involve complete decoherence is to use (and see it in)

$$P_{\alpha\beta} = \sum_i |\langle \nu_\beta | \nu_i \rangle|^2 |\langle \nu_\alpha | \nu_i \rangle|^2$$

i.e., the original and final flavor states are projected onto the mass eigenstates and the mass eigenstates are propagated independently (complete decoherence).

A somewhat different point-of-view:
“Probing Quantum Decoherence with High-Energy Neutrinos”
Hooper, Morgan and Winstanley

Within the context of standard quantum mechanics, a pure state will never oscillate into a superposition or mixture of states. If quantum fluctuations of the gravitational field are considered, however, this may not be the case. Microscopic black holes forming for short periods of time can lead to a loss of quantum information, potentially converting a pure state into a mixture or superposition of quantum states [1,2]. If evidence of this effect, called quantum decoherence, were observed, it could reveal clues about the quantum nature of gravity with incredible implications for string theory, cosmology and particle physics.

As neutrinos propagate, the effects of quantum decoherence would alter the ratios of their flavors toward the values, $\nu_e : \nu_\mu : \nu_\tau \cong \frac{1}{3} : \frac{1}{3} : \frac{1}{3}$, regardless of their initial flavor content. If a flux of neutrinos were to be observed from a astrophysical source with a ratio of flavors differing from $\frac{1}{3} : \frac{1}{3} : \frac{1}{3}$, strong constraints could be placed on the scale of quantum decoherence.

Neutrons are an interesting source of (anti)neutrinos for our purposes because they produce neutrinos in only the electron flavor, *i.e.* $n \rightarrow p\, e^- \bar{\nu_e}$. After standard oscillations, this purely electron anti-neutrino beam converts approximately as 1:0:0 $\rightarrow$ 0.56:0.24:0.20. If a cosmic neutrino source were to be found with such a ratio, this could be used to constrain the scale of quantum decoherence in the neutrino sector. Alternatively, if we could be confident that a source produced neutrinos mostly via neutron decay, the observation of equal quantities of each neutrino flavor from such a source could potentially constitute a discovery of quantum decoherence effects.

$$R = \phi_{\alpha}/(\phi_e + \phi_{\tau}) = \phi_{\alpha}/(Total - \phi_{\alpha})$$

Neutron Beam Source	Pion beam Source	Muon damped Sourde
Neutron decays	Pion decays	Pi decay with absorbed muon
(e:mu:tau)		
(1:0:0)	(1:2:0)	(0:1:0)
R~0.26	R~0.5	R~0.66

After very long distances the neutrinos will oscillate equally into all flavors: (1/3:1/3:1/3)
R then would be: (1/3)/(1/3+1/3)=0.5 as seen in the pion beam source.
This is exactly equivalent to total de-coherence of the 3 flavors.

If the neutrinos de-cohere, R will be 0.5 in every case.
If oscillations occur, the R's will average to the values:

$R_n = 0.36$
$R_\mu = 0.59$

The values agree with Hooper, Morgan and Winstanley:
"Probing Quantum Decoherence with High-Energy Neutrinos"
However, the conclusions are contradictory:
If decoherence, then all R =0.5;
If no decoherence, the R is 0.36 or 0.59 depending on the source.

In order to calculate Eqs. 2 to 4, I used the definition of R, but in these probabilities And expanded the whole thing in theta13. That is not really a back of the envelope calculation, it may actually be easier to go one step back and look at this dependence already on the probability level -- see, e.g., hep-ph/0502088 (equ. 3).

"Measuring the 13-mixing angle and the cP phase with neutrino telescopes": by Serpica and Kacheirreiss.

$$P_{\nu_\alpha \to \nu_\beta}(L) = \left| \sum_k U^*_{\alpha k}\, e^{-im_k^2 L/2E}\, U_{\beta k} \right|^2$$

$$= \sum_k |U_{\alpha k}|^2\, |U_{\beta k}|^2 + 2\,\mathrm{Re} \sum_{k>j} U^*_{\alpha k}\, U_{\beta k}\, U_{\alpha j}\, U^*_{\beta j}\, \exp\left(-i\frac{\Delta m^2_{kj} L}{2E}\right), \qquad (3.9)$$

Flavor composition after oscillations.—The fluxes ϕ_β^D arriving at the detector are given in terms of the probabilities $P_{\alpha\beta} \equiv P(\bar\nu_\alpha \to \bar\nu_\beta)$ [34] by

$$\phi_\beta^D = \sum_\alpha P_{\alpha\beta}\phi_\alpha = P_{e\beta}\,\phi_e\,, \qquad (1)$$

where we have inserted $\phi_\alpha = (\phi_e, 0, 0)$. Since the galactic distances far exceed the experimentally known oscillation lengths even at PeV energies, the interference terms sensitive to the mass splittings Δm^2's in the usual oscillation formula average-out. Then we can write

$$P_{e\beta} = \delta_{e\beta} - 2\sum_{j>k} \mathrm{Re}(U^*_{\beta j} U_{\beta k} U_{ej} U^*_{ek})\,, \qquad (2)$$

where U is the neutrino mixing matrix and greek (latin) letters are used as flavor (mass) indices.

To obtain a feeling for the dependence of the fluxes on ϑ_{13} and $\delta_{\rm CP}$, we give an expansion of $P_{e\beta}$ up to second order in ϑ_{13} where we use $\vartheta_{12}=\frac{\pi}{6}$ and $\vartheta_{23}=\frac{\pi}{4}$,

$$\begin{aligned}
P_{ee} &\approx \frac{5}{8}-\frac{5}{4}\vartheta_{13}^2 \\
P_{e\mu} &\approx \frac{3}{16}+\frac{\sqrt{3}}{8}\vartheta_{13}\cos\delta_{\rm CP}+\frac{5\vartheta_{13}^2}{8} \\
P_{e\tau} &\approx \frac{3}{16}-\frac{\sqrt{3}}{8}\vartheta_{13}\cos\delta_{\rm CP}+\frac{5\vartheta_{13}^2}{8}\,.
\end{aligned} \tag{3}$$

As expected, the survival probability P_{ee} (or equivalently ϕ_e^D) does not depend on $\delta_{\rm CP}$ and the unitarity relation $\sum_\beta P_{e\beta}=1$ holds at each order in ϑ_{13}. Moreover, the $\bar\nu_\mu$ and $\bar\nu_\tau$ fluxes depend on $\delta_{\rm CP}$ only via the quantity $\cos\delta_{\rm CP}$. Note that the independence of P_{ee} from ϑ_{23} and $\delta_{\rm CP}$, as well as the relation $P_{e\mu}=P_{e\tau}(\vartheta_{23}\to\vartheta_{23}+\pi/2)$ (which shows up in the opposite signs of the $\cos\delta_{\rm CP}$ terms in Eq. (3)) hold exactly [26]. Though the approximate relations Eq. (3) are useful to grasp the main features of the dependence of the fluxes ϕ_α^D on ϑ_{13} and $\delta_{\rm CP}$, in the following we will use the exact expressions given in Eq. (2). For all numerical examples, we fix the value of the solar mixing angle to $\vartheta_{12}=32.5^\circ$ [1].

As expected, P_{e \mu} depends on cos deltacp and theta13, while the CP violating dependence averages out.
Note that it is, in general, an often believed rumor that averaged probablities do not depend on deltacp ...(though they do not violate CP!)

$$U = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

$$\vartheta_{12} = \pi/6 \qquad \vartheta_{23} = \pi/4$$

$$c_{12} = 0.866 = \sqrt{3}/2 \qquad s_{12} = 1/2$$

$$c_{23} = s_{23} = 1/\sqrt{2}$$

$$U = \begin{bmatrix} \sqrt{3}c_{13}/2 & c_{13}/2 & s_{13}e^{-i\delta} \\ -1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8} & \sqrt{3/8} - s_{13}e^{i\delta}/\sqrt{8} & c_{13}/\sqrt{2} \\ 1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8} & -\sqrt{3/8} - s_{13}e^{i\delta}/\sqrt{8} & c_{13}/\sqrt{2} \end{bmatrix}$$

$$P_{e\beta} = \delta_{e\beta} - 2\sum_{j>k} \mathrm{Re}(U^*_{\beta j} U_{\beta k} U_{ej} U^*_{ek})$$

$$P_{ee} = 1 - 2(3c^4_{13}/16 + 3s^2_{13}c^2_{13}/4 + s^2_{13}c^2_{13}/4)$$

$$P_{ee} = 1 - 2(3c^4_{13}/16 + s^2_{13}c^2_{13})$$

$$P_{ee} = (c^2_{13} + s^2_{13})^2 - 3c^4_{13}/8 - 2s^2_{13}c^2_{13}$$

$$P_{ee} = c^4_{13} + 2s^2_{13}c^2_{13} + s^4_{13} - 3c^4_{13}/8 - 2s^2_{13}c^2_{13}$$

$$P_{ee} = 5c^4_{13}/8 + s^4_{13}$$

$$c_{13} \sim 1 - \vartheta^2_{13}/2$$

$$c^2_{13} \sim 1 - \vartheta^2_{13}$$

$$c^4_{13} \sim 1 - 2\vartheta^2_{13}$$

$$s^4_{13} \sim 0$$

$$P_{ee} \sim 5/8 - 5/4\vartheta^2_{13}$$

$$P_{e\mu} = -2\{\mathrm{Re}(U^*_{\mu 2}U_{\mu 1}U_{e2}U^*_{e1}) + \mathrm{Re}(U^*_{\mu 3}U_{\mu 1}U_{e3}U^*_{e1}) + \mathrm{Re}(U^*_{\mu 3}U_{\mu 2}U_{e3}U^*_{e2})\}$$

$$U = \begin{bmatrix} \sqrt{3}c_{13}/2 & c_{13}/2 & s_{13}e^{-i\delta} \\ -1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8} & \sqrt{3/8} - s_{13}e^{i\delta}/\sqrt{8} & c_{13}/\sqrt{2} \\ 1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8} & -\sqrt{3/8} - s_{13}e^{i\delta}/\sqrt{8} & c_{13}/\sqrt{2} \end{bmatrix}$$

$$P_{e\mu} = -2\{\mathrm{Re}(U^*_{\mu 2}U_{\mu 1}U_{e2}U^*_{e1}) + \mathrm{Re}(U^*_{\mu 3}U_{\mu 1}U_{e3}U^*_{e1}) + \mathrm{Re}(U^*_{\mu 3}U_{\mu 2}U_{e3}U^*_{e2})\}$$

$$P_{e\mu} = -2\{\mathrm{Re}\,A + \mathrm{Re}\,B + \mathrm{Re}\,C\} \quad A = (U^*_{\mu 2}U_{\mu 1}U_{e2}U^*_{e1})$$

$$A = (\sqrt{3/8} - s_{13}e^{-i\delta}/\sqrt{8})(-1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8})(c_{13}/2)(\sqrt{3}c_{13}/2)$$

$$A = (-\sqrt{3}/8 - 3s_{13}e^{i\delta}/8 + s_{13}e^{-i\delta}/8 + \sqrt{3}s_{13}^2/8)(\sqrt{3}c_{13}^2/4)$$

$$\mathrm{Re}\,A = (-\sqrt{3}/8 - s_{13}\cos\delta/4 + \sqrt{3}s_{13}^2/8)(\sqrt{3}c_{13}^2/4)$$

$$B = (c_{13}/\sqrt{2})(-1/\sqrt{8} - \sqrt{3}s_{13}e^{i\delta}/\sqrt{8})(s_{13}e^{-i\delta})(\sqrt{3}c_{13}/2)$$

$$\mathrm{Re}\,B = (-1/\sqrt{8} - \sqrt{3}s_{13}\cos\delta/\sqrt{8})(s_{13}\cos\delta)(\sqrt{3}c_{13}^2/2\sqrt{2})$$

$$C = (c_{13}/\sqrt{2})(\sqrt{3/8} - s_{13}e^{i\delta}/\sqrt{8})(s_{13}e^{-i\delta})(c_{13}/2)$$

$$\mathrm{Re}\,C = (\sqrt{3/8} - s_{13}\cos\delta/\sqrt{8})(s_{13}\cos\delta)(c_{13}^2/2\sqrt{2})$$

$$\mathrm{Re}\,A = (-\sqrt{3}/8 - s_{13}\cos\delta/4 + \sqrt{3}s_{13}^2/8)(\sqrt{3}c_{13}^2/4)$$

$$\mathrm{Re}\,B = (-1/\sqrt{8} - \sqrt{3}s_{13}\cos\delta/\sqrt{8})(s_{13}\cos\delta)(\sqrt{3}c_{13}^2/2\sqrt{2})$$

$$\mathrm{Re}\,C = (\sqrt{3/8} - s_{13}\cos\delta/\sqrt{8})(s_{13}\cos\delta)(c_{13}^2/2\sqrt{2})$$

$$s_{13}^2 \sim 0$$

$$c_{13}^2 \sim 1$$

$$\mathrm{Re}\,A = (-\sqrt{3}/8 - s_{13}\cos\delta/4)(\sqrt{3}/4)$$

$$\mathrm{Re}\,B = (-s_{13}\cos\delta/\sqrt{8})(\sqrt{3}/2\sqrt{2})$$

$$\mathrm{Re}\,C = (\sqrt{3/8}s_{13}\cos\delta)(1/2\sqrt{2})$$

$$P_{e\mu} = -2\{-3/32 + s_{13}\cos\delta(\sqrt{3}/8 - \sqrt{3}/8 - \sqrt{3}/16)\}$$

$$P_{e\mu} = 3/16 + s_{13}\cos\delta(\sqrt{3}/8)$$

I convinced myself that the calculation is correct, but I can be certain that I Understand the basic premise.

Nuclear Effects in Neutrino Induced Coherent Pion Production at K2K and MiniBooNE Neutrino Energies

S. K. Singh, M. Sajjad Athar and Shakeb Ahmad
Department of Physics, Aligarh Muslim University, Aligarh- 202002, India.

The coherent pion production induced by neutrinos in nuclei is studied using a delta hole model in local density approximation taking into account the renormalization of Δ properties in a nuclear medium. The pion absorption effects have been included in an eikonal approximation. These effects give a large reduction in the total cross section. The numerical results for the total cross section are found to be consistent with recent experimental results from K2K and MiniBooNE collaborations and other older experiments in the intermediate energy region.

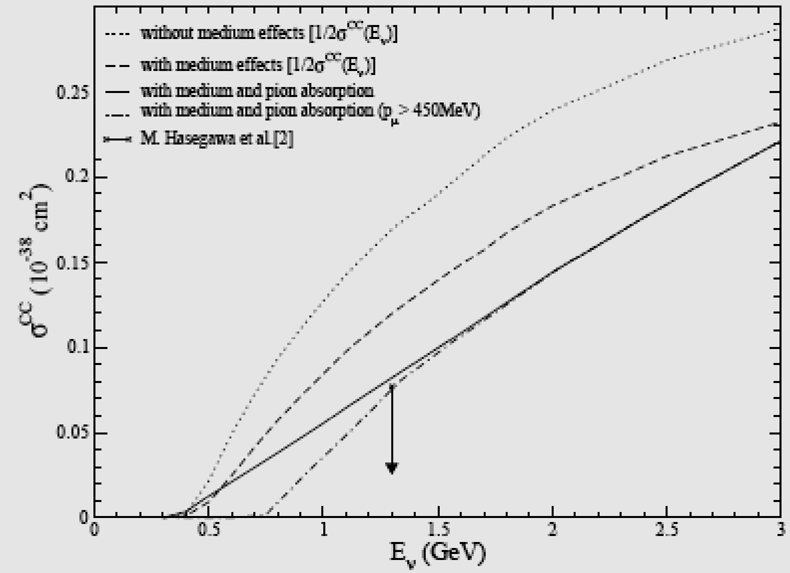


FIG. 2: $\sigma(E_\nu)$ vs E_ν for coherent π^+ production in ^{12}C (see text for details).

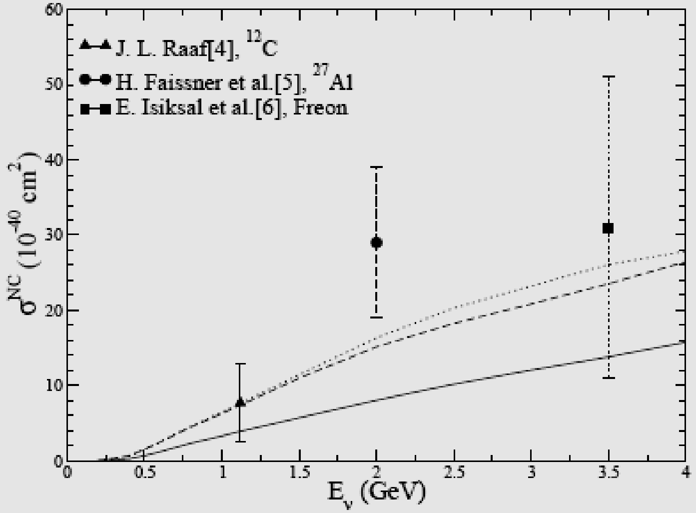
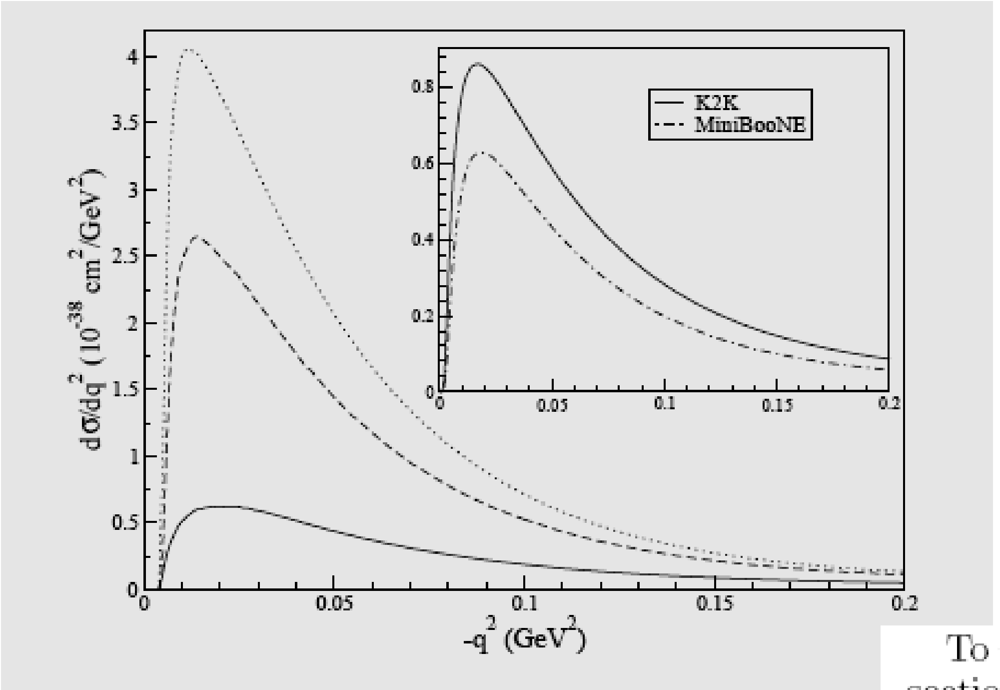
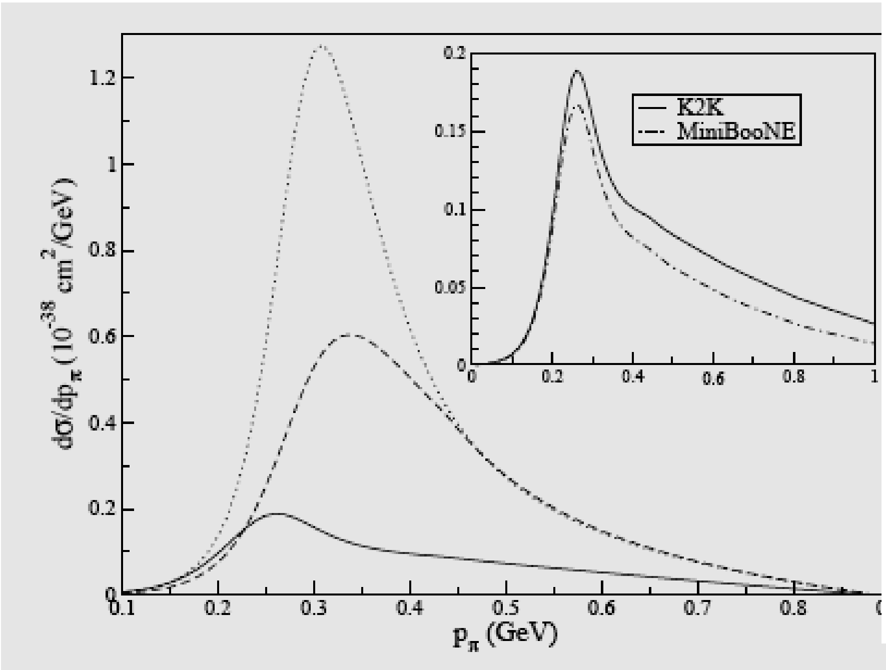


FIG. 3: $\sigma(E_\nu)$ vs E_ν for coherent π^0 production in ^{12}C(solid), ^{27}Al(dashed) and Freon(dotted) with nuclear medium and pion absorption effects, along with the experimental results [4]-[6]



They only cite Jen Raff's thesis, which
Doesn't contain these curves.



To summarize, we have studied in this letter total cross section $\sigma(\mathrm{E}_\nu)$, differential cross sections $\frac{\mathrm{d}\sigma}{\mathrm{d}q^2}$ and $\frac{\mathrm{d}\sigma}{\mathrm{d}p_\pi}$ for the neutrino induced coherent production of charged and neutral pions in a model, which takes into account nuclear medium effects in the weak pion production process through Δ dominance treated in local density approximation. The final state interaction of pions with the nucleus is described in an eikonal approximation with a pion optical potential derived in terms of the pion self energy in the nuclear medium. The good agreement between the theoretical and experimental results in the energy region of 1 GeV is obtained mainly due to inclusion of nuclear medium and pion absorption effects. The method may be useful to analyze the neutrino induced pion production data at neutrino energies relevant for neutrino oscillation experiments being done by K2K, MiniBooNE and J-PARC collaborations.

Neutrino masses and mixing parameters in a left-right model with mirror fermions

R. Gaitán[2], A. Hernández-Galeana[1,*], J. M. Rivera-Rebolledo[1,†]
and P. Fernández de Córdoba[3]

Fermion masses in a model for spontaneous parity breaking

Y.A. Coutinho[1,a], J.A. Martins Simões[1,b], C.M. Porto[2]

The basic idea:

$$SU(2)_L \otimes U(1)_Y \rightarrow SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$

Introduce 2 sets of leptons:

$$\ell_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L, \nu_R, e_R \overset{\mathbf{P}}{\leftrightarrow} \mathrm{L_R} = \begin{pmatrix} N \\ E \end{pmatrix}_R, N_{\mathrm{L}}, E_L$$

The ratio of vev from SSB:

$$\omega = \mathrm{v_L} / \mathrm{v_R} << 1$$

	doublet			neutrino			electron		
	T_2	T_1	Y	T_2	T_1	Y	T_2	T_1	Y
Left	1/2	0	-1	0	0	0	0	0	-2
Right	0	1/2	-1	0	0	0	0	0	-2

Standard Model:

$$\mathrm{e} = \mathrm{g_W} \sin(\vartheta_W)$$

New Model:

$$\mathrm{e} = \mathrm{g_L} \sin(\vartheta_W)$$

The new coupling constants are:

$(\mathrm{g_L}; g_R; g')$ g' replaces e as the EM coupling constant.

New Model:

$$\sin^2\vartheta_W = \frac{g_R^2 g'^2}{g_R^2 g_L^2 + g_R^2 g'^2 + g_L^2 g'^2}$$

$$\sin^2\beta = \frac{g'^2}{g_R^2 + g'^2}$$

But $\mathrm{g_R} = g_L$ because of the symmetry under parity operations.

$$M_\gamma = 0$$

$$M_Z^2 = \frac{1}{4}\frac{v_L^2 g_L^2}{\cos^2(\vartheta_W)}\{1-\omega^2\sin^4\beta\}$$

$$M_{Z'}^2 = \frac{1}{4} v_R^2 g_L^2 \tan^2\vartheta_W \{1 + \frac{\omega^2 \sin^2 2\beta}{4\sin^2\vartheta_W}\}$$

Compare to the Standard Model:

$$\mathrm{M}_{Z^0} = \frac{M_{W^+}}{\cos\vartheta_W}$$

The ratio of neutral to charged current couplings is 1.0 in the simplest Weinberg model.

In the New Model:

$$\rho = \frac{\mathrm{M}_{\mathrm{W_L}}^2}{\mathrm{M}_{\mathrm{Z}}^2 \cos^2\vartheta_W}\{1-\omega^2\sin^4\beta\}$$

The neutral currents coupled to the massive vector bosons Z and Z' are J_μ and J'_μ

Comparing to existing data, a bound can be set on ω and the ratio of left and right vev:

$$v_R > 30 v_L$$

$$M_{z'} > 800\,\mathrm{GeV}$$

To generate fermion masses, they need to add additional scalar Higgs bosons to the Lagrangian. They also include Dirac and Majorana terms.

s_D

$$M_{\nu,N} = \begin{pmatrix} 0 & \frac{k}{2} & v_L & \frac{v_L}{2} \\ \frac{k}{2} & 0 & \frac{v_R}{2} & v_R \\ v_L & \frac{v_R}{2} & s_M & \frac{s_D}{2} \\ \frac{v_L}{2} & v_R & \frac{s_D}{2} & s_M \end{pmatrix} \qquad M_{e,E} = \begin{pmatrix} 0 & \frac{k'}{2} & 0 & v_L \\ \frac{k'}{2} & 0 & v_R & 0 \\ 0 & v_R & 0 & s_D \\ v_L & 0 & s_D & 0 \end{pmatrix}$$

v = vev
k = constant in SSB
s = D/M coupling const.

These folks would like to see LSND confirmed:
They really need that fourth term in the mixing matrix!

Some predictions:

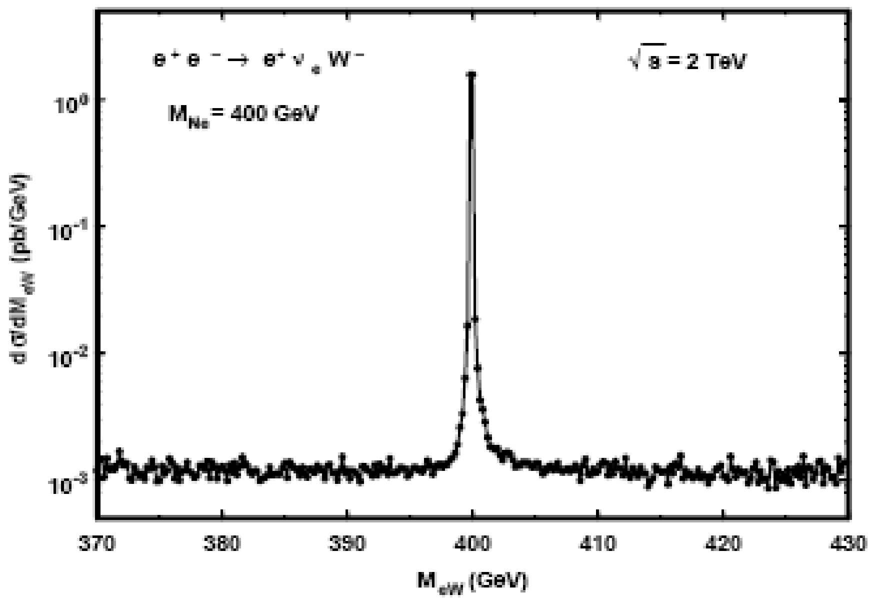


Fig. 2. Invariant eW mass distribution in the process $e^+e^- \rightarrow e^+ \nu_e W^-$ at NLC with $s^{1/2} = 2\,\mathrm{TeV}$ and $M_{Ne} = 400\,\mathrm{GeV}$. The flat part of the curve is the standard model background

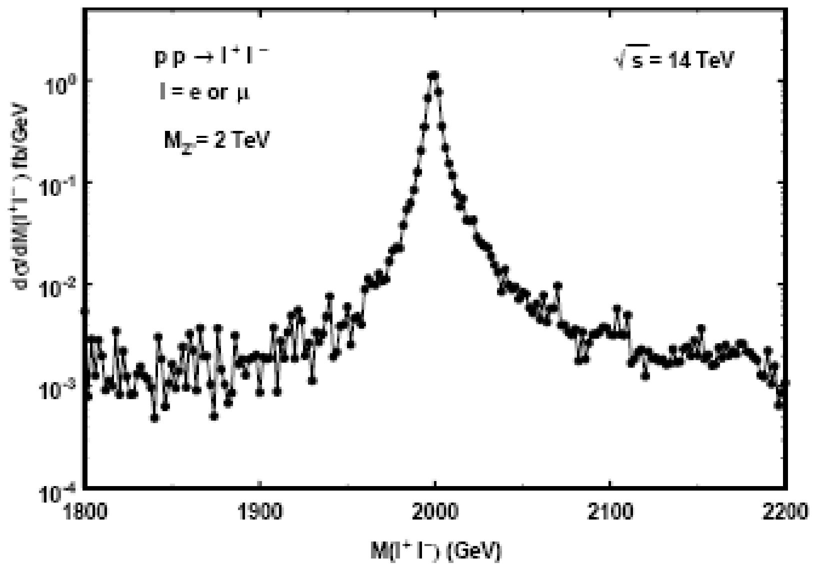


Fig. 3. The invariant mass distribution for $pp \longrightarrow Z' \rightarrow \ell^{\pm}\ell^{\mp}$ (where $\ell = e$ or μ) for pp collisions at LHC with $s^{1/2} = 14\,\mathrm{TeV}$, $E > 20\,\mathrm{GeV}$ and $|\eta| < 2,5$ and $M_{Z'} = 2\,\mathrm{TeV}$